

## TIG WELDING EQUIPMENT AND TIG WELDING METHOD

### 5 CROSS-REFERENCE TO RELATED APPLICATION

This application claims the priority benefit of Japanese patent application serial no. 2003-076318, filed on March 19, 2003.

### BACKGROUND OF THE INVENTION

#### Field of the Invention

[0001] The present invention relates to a welding equipment used in tungsten-inert-gas (TIG) weld of steel-based materials, and a welding method using the welding equipment.

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#### Description of Related Art

[0002] Conventionally, a structure using a steel-based material, such as, carbon steel or stainless steel, as a base material is welded with TIG weld. TIG weld is widely used as a method of welding structures requiring high reliability for easy performance and formation of high-quality welded metal portion, as described in, for example, Japanese Patent Application Laid Open No. 2003-019561.

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[0003] However, since the steel-based materials including stainless steel used in recent years usually contain less sulfur as an impurity, the welded metal portion has a wide and shallow weld-penetration shape in the TIG welding process so that the welding effect is insufficient. To form a welded metal portion deeply, increasing the number of passes is required. However, when the number of passes is increased, the welding efficiency

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5 is adversely lowered.

[0004] Other welding methods include MAG (metal-active-gas) weld, MIG (metal-inert-gas) weld and plasma weld, etc., which are adopted in cases where deep welded metal portions and high-efficiency welding performance are required. However, the MAG or MIG welding method has some problems including deterioration of welding  
10 quality and occurrence of welding defects. Moreover, plasma weld has a drawback that the tolerance range of groove accuracy or other performance condition is so narrow making the method difficult to use in a construction site or the like.

[0005] A method for improving the drawback of shallow welded metal portion that is significant in TIG weld has been proposed, utilizing a shielding gas composed of a  
15 mixed gas obtained by mixing an inert gas like argon with hydrogen or helium, etc. Moreover, another TIG welding method using active flux, i.e., the A-TIG welding method, has also been proposed recently.

[0006] However, the welding method that uses a shielding gas containing hydrogen is difficult to apply to a material other than austenitic stainless steel because of some  
20 problems including generation of blowholes and embrittlement of the welded metal portion. In addition, using helium is not preferable in consideration of the cost. Moreover, the workability of the method using active flux is poor, since a coating operation is required before the welding process. Moreover, since slag is generated remarkably on the weld bead, slag removal is required in multi-layer weld to prevent  
25 degradation of the bead appearance. Furthermore, a lot of fume is generated in the above welding method, so that the work environment is worse.

[0007] Moreover, in anode-type (DC electrode positive type) arc welding methods including MAG weld, a shielding gas composed of argon gas mixed with an oxidative

5 component, such as carbon dioxide in a concentration of 20%, is used for improving the stability of electric arc. However, when an oxidative gas is used as a shielding gas in TIG weld, the electrode is easily deteriorated and cannot be used in long-time weld or used repeatedly. If a deteriorated electrode is used, the welding quality is not stable, and weld defects possibly occur.

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### SUMMARY OF THE INVENTION

[0008] In view of the foregoing, this invention provides a TIG welding equipment and a TIG welding method, which can form a deep welded metal portion without lowering the welding quality and make the welding performance easier, as well as improves the welding efficiency.

15 [0009] After studying the issue with effort, the inventor found that the shape of the welded metal portion is largely affected by convection in the molten pool, while the main factor affecting the convection is the surface tension distribution caused by the temperature distribution in the molten pool. This invention is made based on the above discovery. A TIG welding equipment of this invention includes an electrode for generating an electric arc between itself and the welded object, a tubular inner nozzle disposed surrounding the electrode, and a tubular outer nozzle disposed surrounding the inner nozzle. A first shielding gas including an inert gas can be supplied from the inner nozzle, and a second shielding gas containing an oxidative gas can be supplied

20 from between the inner nozzle and the outer nozzle. A TIG welding equipment according another embodiment of this invention includes an electrode for generating an electric arc between itself and the welded object, a tubular central nozzle disposed surrounding the electrode, and side nozzles disposed at least on two sides of the

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5 electrode as view in the welding direction. The central nozzle can supply a first shielding gas including an inert gas, and the side nozzles can supply a second shielding gas containing an oxidative gas.

[0010] In an embodiment of the TIG welding method according to this invention, an electric arc is generated between an electrode and an object for welding the object. A  
10 first shielding gas including an inert gas is conducted toward the object surrounding the electrode, and a second shielding gas containing an oxidative gas is conducted toward the object along the periphery of the first shielding gas. In another embodiment of the TIG welding method, an electric arc is generated between the electrode and an object for welding the object. A first shielding gas including an inert gas is conducted toward  
15 the object surrounding the electrode, and a second shielding gas containing an oxidative gas is conducted toward the object from at least two sides of the electrodes as viewed in the welding direction. In both methods, the concentration of the oxidative gas in the second shielding gas preferably ranges from 2000 vol. ppm to 6000 vol. ppm, and more preferably from 3000 vol. ppm to 5000 vol. ppm. Moreover, the concentration of the  
20 oxidative gas in the second shielding gas is preferably set so that the oxygen concentration in the welded metal portion ranges from 70 wt. ppm to 220 wt. ppm. In the TIG welding methods of this invention, the oxide coating formed on the surface of the welded metal portion preferably has a thickness of 20 $\mu$ m or less.

[0011] It is to be understood that both the foregoing general description and the  
25 following detailed description are exemplary, and are intended to provide further explanation of the invention as claimed.

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## BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The accompanying drawings are included to provide a further understanding of the invention, and are incorporated in and constitute a part of this specification. The drawings illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention.

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[0013] FIG. 1 schematically illustrates the structure of the important part of a welding equipment according to a first embodiment of this invention.

[0014] FIG. 2(a) shows the correlation between the surface tension and temperature in the molten pool, and FIG. 2(b) is a diagram showing the state of the molten pool.

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[0015] FIG. 3 schematically illustrates the structure of an important part of a welding equipment according to a second embodiment of this invention, wherein FIG. 3(a) illustrates a front view of the equipment with a part thereof shown in a sectional state, and FIG. 3(b) illustrates a cross-sectional view of the equipment.

[0016] FIG. 4 illustrates a planar view of a welded object obtained by using the welding equipment shown in FIG. 3.

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[0017] FIG. 5 schematically illustrates the structure of the important part of a welding equipment according to a third embodiment of this invention, wherein FIG. 5(a) illustrates a front view of the equipment with a part thereof shown in a sectional state, and FIG. 5(b) illustrates a cross-sectional view of the equipment.

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[0018] FIG. 6 schematically illustrates the structure of the important part of a welding equipment according to a fourth embodiment of this invention, wherein FIG. 6(a) illustrates a front view of the equipment with a part thereof shown in a sectional state, and FIG. 6(b) illustrates a cross-sectional view of the equipment.

[0019] FIG. 7 illustrates a planar view of a welded object obtained by using the welding

5 equipment shown in FIG. 6.

[0020] FIG. 8 schematically illustrates the structure of the important part of a welding equipment according to a fifth embodiment of this invention, wherein FIG. 8(a) illustrates a front view of the equipment with a part thereof shown in a sectional state, and FIG. 8(b) illustrates a cross-sectional view of the equipment.

10 [0021] FIG. 9 shows the states of the welded metal portion as the results of the welding tests in a cross-sectional view.

[0022] FIGs. 10-13 are graphs showing the results of the welding tests.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

15 [0023] The welding equipment according to the embodiments of this invention are described below referring to the drawings. The welding equipment certainly includes a welding device, a control device, a gas supply and a welding power, even though they are not shown in the drawings.

20 <First Embodiment>

[0024] FIG. 1 illustrates a welding equipment according to the first embodiment of this invention. Referring to FIG. 1, the TIG welding equipment A is equipped with a torch 1 having a multiple tubular structure that is constituted of a tungsten electrode 2 for generating an electric arc 7 between itself and a base material (welded object) 10, a  
25 tubular inner nozzle 3 disposed surrounding the tungsten electrode 2, and a tubular outer nozzle 4 disposed surrounding the inner nozzle 3. The base material 10 is, for example, a steel-based material. Briefly speaking, the torch 1 is a multiple tubular structure having an inner nozzle 3 disposed at the periphery of the tungsten electrode 2

5 and an outer nozzle 4 at the periphery of the inner nozzle 3.

[0025] The tip (bottom end) of the tungsten electrode 2 is formed more protrudent than that of the inner nozzle 3 in the tip direction (downward direction). The inner nozzle 3 is disposed approximately concentric with the tungsten electrode 2 with a distance from the latter. The inner nozzle 3 can supply a first shielding gas 8 composed of a high-  
10 purity inert gas. The first shielding gas 8 can be argon (Ar) or helium (He), for example.

[0026] The outer nozzle 4 is disposed approximately concentric with the inner nozzle 3 with a distance from the latter, while a second shielding gas 9 containing an oxidative gas can be supplied through the gap between the outer nozzle 4 and the inner nozzle 3.  
15 The second shielding gas 9 can be a mixed gas obtained by adding an oxidative gas into an inert gas. The oxidative gas can be oxygen (O<sub>2</sub>) or carbon dioxide (CO<sub>2</sub>), for example, and the inert gas may be argon or helium.

[0027] The method of welding the base material 10 using the above welding equipment A is described as follows. As shown in FIG. 1, the tungsten electrode 2 serves as a  
20 negative electrode and the base material 10 as a positive electrode, and a voltage is applied between the torch 1 and the base material 10 to induce discharge and generate an electric arc 7. The torch 1 is moved toward the left side of the drawing to melt the base material 10 by the heat from the electric arc 7 to form a molten pool 5, so as to weld the base material 10. Moreover, the weld bead is labeled with a reference  
25 number "6" in the drawing.

[0028] During the welding operation, the first shielding gas 8 is supplied from the inner nozzle 3. The first shielding gas 8 is conducted toward the tip of the inner nozzle 3 surrounding the tungsten electrode 3 and sprayed onto the base material 10 from the tip.

5 The first shielding gas 8 is sprayed onto the central region of the molten pool 5.

[0029] At the same time, the second shielding gas 9 containing an oxidative gas is supplied through the gap between the inner nozzle 3 and the outer nozzle 4. The second shielding gas 9 is conducted toward the tip of the outer nozzle 4 and sprayed to the base material 10 from the tip. At the moment, the second shielding gas 9 is conducted along the periphery of the first shielding gas 8 surrounding the first shielding gas 8, and is sprayed onto the peripheral region (the region located at the periphery of the central region) of the molten pool 5. The concentration of the oxidative gas like O<sub>2</sub> in the second shielding gas 9 is preferably 2000-6000 vol. ppm, and more preferably 3000-5000 vol. ppm. The use of the second shielding gas 9 containing an oxidative gas allows oxygen to be dissolved in the welded metal portion 5a, while the concentration of the oxidative gas in the second shielding gas 9 is preferably set so that the oxygen concentration in the welded metal portion 5a is 70-220 wt. ppm. With the above operation, a welded structure having a welded metal portion 5a is obtained. An oxide coating is also formed on the surface of the welded metal portion 5a, while the thickness of the oxide coating is preferably 20 $\mu$ m or less.

[0030] On the other hand, the surface tension of a melted metal varies with the temperature or the concentration of dissolved trace impurity like sulfur or oxygen. FIG. 2(a) shows an example of correlation between the surface tension and the temperature of a melted metal, wherein sulfur or oxygen is dissolved in the welded metal in certain concentration. According to FIG. 2(a), the surface tension increases with increasing temperature. In this case, the temperature in the peripheral region R2 of the molten pool 5 is lower than that in the central region R1, so that the surface tension in the peripheral region R2 is smaller than that in the central region R1 causing



5 inward convection in the molten pool 5, as shown in FIG. 2(b). Moreover, even if the temperature is constant, the surface tension decreases with the increase in the concentration of oxygen dissolved in melted iron.

[0031] Because the welding equipment A is equipped with a torch 1 having a tubular inner nozzle 3 surrounding the tungsten electrode 2 and a tubular outer nozzle 4  
10 surrounding the inner nozzle 3, the following effects are obtained.

(1) Since the first shielding gas 8 is conducted surrounding the tungsten electrode 2, the tungsten electrode 2 is protected by the first shielding gas 8, and can be prevented from being deteriorated by oxidation. Therefore, the welded structure can be obtained with good welding quality.

15 (2) Since the second shielding gas 9 is supplied from the gap between the inner nozzle 3 and the outer nozzle 4, it is possible to supply the first shielding gas 8 to the central region R1 of the molten pool 5 and simultaneously supply the second shielding gas 9 containing an oxidative gas to the peripheral region R2 of the molten pool 5. Thereby, the molten pool 5 can be supplied with oxygen in a required concentration,  
20 and the oxygen concentration in the peripheral region R2 can be higher than that in the central region R1. Therefore, in the molten pool 5, the surface tension in the peripheral region R2 having lower temperature and higher oxygen concentration is smaller, and that in the central region R1 having higher temperature and lower oxygen concentration is larger. Consequently, inward convection is induced in the  
25 molten pool 5 so that and the molten pool 5 can be formed deeply. Therefore, the welded metal portion 5a can be formed deeply in the base material 10.

(3) As compared with the conventional welding method using active flux, slag is hardly generated in this invention so that a slag removal operation is not required.

5       Meanwhile, fume is also hardly generated during the welding process. Therefore, the welding operation can be easily carried out.

(4) Since the welded metal portion can be formed deeply, occurrence of poor weld-penetration or reduction in welding efficiency can be prevented.

10    **<Second Embodiment>**

[0032] FIG. 3 illustrates a welding equipment according to the second embodiment of this invention. In the drawing and the following description, the parts similar to those in the welding equipment A of FIG. 1 are also labeled with the same reference numbers and the description thereof is not repeated again. Moreover, the “welding direction” is defined as the moving direction of the torch hereinafter, the “front side” is the side along the welding direction, and the “back side” is the side against the welding direction.

[0033] The welding equipment B is equipped with a torch 11 that includes a tungsten electrode 2, a central nozzle 13 disposed surrounding the tungsten electrode 2, and side nozzles 14 disposed between the tungsten electrode 2 and the central nozzle 13. That is, the torch 11 has a structure including a central nozzle 13 disposed at the periphery of the tungsten electrode 2 and side nozzles 14 disposed between the tungsten electrode 2 and the central nozzle 13.

[0034] The central nozzle 13 is disposed approximately concentric with the tungsten electrode 2 with a distance from the latter, capable of supplying the first shielding gas 8.

[0035] Referring to FIG. 3(b), a side nozzle 14 is disposed on each of the two sides of the tungsten electrode 2 along the welding direction. The side nozzles 14 can supply the second shielding gas 9, and are preferably formed with tips more protrudent than

5 that of the central nozzle 13 in the tip direction. Moreover, the side nozzles 14 may be alternatively disposed at least with their tips on sides of the tungsten electrode 2 without directly spraying the second shielding gas 9 onto the weld bead.

[0036] As shown in FIGs. 3 and 4, when the welding equipment B is being used to weld the base material 10, the torch 11 is moved to melt the base material 10 by the electric  
10 arc 7 to form a molten pool 15, so as to weld the base material 10. The weld bead is labeled with a reference number "16" in the drawing. During the welding operation, the first shielding gas 8 is supplied from the central nozzle 13. The first shielding gas 8 is conducted toward the tip of the central nozzle 13 surrounding the tungsten electrode 2 and sprayed onto the base material 10 from the tip. At the same time, the second  
15 shielding gas 9 is supplied from the side nozzles 14. The second shielding gas 9 is conducted toward the tips of the side nozzles 14 and sprayed onto the base material 10 from the tips. Since the second shielding gas 9 is conducted along the periphery of the first shielding gas 8 and sprayed on side portions of the peripheral region of the molten pool 15, the second shielding gas 9 is not supplied to the central region even if the torch  
20 11 is moved in high speed. Thereby, a welded structure having a welded metal portion 15a is obtained.

[0037] Since the welding equipment B is equipped with a torch 11 including a tubular central nozzle 13 disposed surrounding the tungsten electrode 2 and side nozzles 14 disposed between the tungsten electrode 2 and the central nozzle 13, the tungsten  
25 electrode 2 can be protected from being deteriorated by oxidation, as in the case using the welding equipment A illustrated in FIG. 1. Therefore, the welded structure can be obtained with good welding quality. Moreover, since the second shielding gas 9 containing an oxidative gas can be supplied to the peripheral region of the molten pool

5 15, the inward convection in the molten pool 15 is enhanced so that the molten pool 15 can be formed deeply. Therefore, the welded metal portion 15a can be formed deeply in the base material 10. Furthermore, using the welding equipment B makes the welding performance easier and improves the welding efficiency.

[0038] In this invention, one or more side nozzles can further be disposed on the front  
10 side and/or the back side of the electrode. Referring to FIG. 5 that illustrates a welding equipment according to the third embodiment of this invention, the welding equipment B' differs from the welding equipment B illustrated in FIG. 3 in that two more side nozzles 14a and 14b are further included. The two side nozzles 14a and 14b are disposed on the front side and the back side, respectively, of the tungsten electrode 2  
15 between the tungsten electrode 2 and the central nozzle 13, capable of supplying the second shielding gas 9.

[0039] FIG. 6 illustrates a welding equipment according to the fourth embodiment of this invention. The welding equipment C differs from the welding equipment B illustrated in FIG. 3 in that the side nozzles 24 are disposed outside the central nozzle  
20 23. That is, the welding equipment is equipped with a torch 21 including a tungsten electrode 2, a tubular central nozzle 23 disposed surrounding the tungsten electrode 2, and side nozzles 24 disposed outside the central nozzle 23.

[0040] The side nozzles 24 are arranged so that each of the two sides of the tungsten electrode 2 as viewed in the welding direction is disposed with a side nozzle 24, and are  
25 preferably formed with tips more protrudent than that of the central nozzle 23 in the tip direction. The side nozzles 24 can supply the second shielding gas 9. Moreover, the side nozzles 24 may be alternatively disposed at least with their tips on sides of the tungsten electrode 2 without directly spraying the second shielding gas 9 onto the weld

5 bead. Furthermore, the welding direction is varied with the arrangement of the welded part, but the side nozzles 24 are constantly kept on two sides of the tungsten electrode 2 as view in the welding direction even when the welding direction is changed by 90 degrees, for example.

[0041] As shown in FIG. 7, when the welding equipment C is being used to weld the  
 10 base material 10, the electric arc 7 melts the base material 10 to form a molten pool 25 so that the base material 10 can be welded. The weld bead is labeled with a reference number "26" in FIG. 7. During the welding operation, the first shielding gas 8 is supplied from the central nozzle 23. The first shielding gas 8 is conducted toward the tip of the central nozzle 23 surrounding the tungsten electrode 2 and sprayed onto the  
 15 base material 10 from the tip. At the same time, the second shielding gas 9 is supplied from the side nozzles 24. The second shielding gas 9 is conducted toward the tips of the side nozzles 24 and sprayed onto the base material 10 from the tips. More specifically, the second shielding gas 9 is sprayed onto two side portions of the peripheral region of the molten pool 25. Thereby, a welded structure having the  
 20 welded metal portion 25a is obtained.

[0042] Since the welding equipment C is equipped with a torch 21 including a tubular central nozzle 23 disposed surrounding the tungsten electrode 2 and side nozzles 24 disposed outside the central nozzle 23, the tungsten electrode 2 can be protected from being deteriorated by oxidation, as in the case using the welding equipment A illustrated  
 25 in FIG. 1. Therefore, the welded structure can be obtained with good welding quality. Moreover, since the second shielding gas 9 containing an oxidative gas is supplied to the peripheral region of the molten pool 25, the inward convection in the molten pool 25 is enhanced so that the molten pool 25 can be formed deeply. Therefore, the welded

- 5 metal portion 25a can be formed deeply in the base material 10. Furthermore, using the welding equipment C makes the welding performance easier and improves the welding efficiency. In addition, since the side nozzles 24 are disposed outside the central nozzle 23, the second shielding gas 9 can be supplied certainly along the periphery of the first shielding gas 8.
- 10 [0043] In this invention, one or more side nozzles can be further disposed on the front and/or the back side of the electrode. Referring to FIG. 8 that illustrates a welding equipment according to the fifth embodiment of this invention, the welding equipment C' differs from the welding equipment C in FIG. 6 in that two more side nozzles 24a and 24b are further included. The two side nozzles 24a and 24b are disposed on the
- 15 front side and the back side, respectively, of the tungsten electrode 2 outside the central nozzle 23, capable of supplying the second shielding gas 9.
- [0044] Moreover, in the above welding equipment B, B', C or C', the side nozzles 14 or 24 are not necessarily disposed exactly on two sides of the tungsten electrode 2, and their positions may deviate forward or backward.
- 20 [0045] Some examples of this invention are described as follows. In the examples, SUS304-type stainless steel having low sulfur concentration is used as the base material 10. The compositional components of the stainless steel are listed in Table 1.

Table 1

Component	C	Si	Mn	Ni	Cr	P	S	O	Fe
Amount (wt%)	0.06	0.44	0.96	8.19	18.22	0.027	0.001	0.0038	---

- 25 [0046] In the examples, the welding equipment A illustrated in FIG. 1 is used, the first

5 shielding gas 8 is argon, and the second shielding gas 9 is a mixed gas obtained by adding oxygen ( $O_2$ ) as an oxidative gas into argon as an inert gas. Some welding tests of the base material 10 are performed under the above conditions, and then the cross sections of the welded metal portions 5a are observed. In the welding tests, the oxygen concentration in the second shielding gas 9 ranges from 1000-9000 vol. ppm, and the flow rate of the second shielding gas 9 is 10L/min or 20L/min. The cross section of the welded metal portion 5a obtained in each test is shown in FIG. 9, while the testing result obtained by using pure argon instead of the second shielding gas 9 is also included for comparison. The other welding conditions are listed in Table 2.

15 Table 2

Item	Condition
Type of electrode	DCEN, W-2%ThO <sub>2</sub> (tungsten electrode containing 2% of thorium)
Diameter of electrode	1.6mm
Tip angle of electrode	60°
Shielding gas	Ar gas, O <sub>2</sub> /Ar mixed gas
Flow rate of gas	10L/min or 20L/min
Arc length	3mm
Bead length	50mm
Welding time	3 seconds
Welding current	160A
Welding speed	2mm/sec

[0047] As shown in FIG. 9, the welded metal portion 5a can be formed more deeply in the tests using the second shielding gas 9 containing oxygen, as compared with the tests

5 using pure argon ( $O_2$  concentration = 0 vol. ppm) instead of the second shielding gas 9. Moreover, when the oxygen concentration in the second shielding gas 9 is within the range of 2000-6000 vol. ppm, especially within the range of 3000-5000 vol. ppm, the welded metal portion 5a is formed deeply in particular.

[0048] FIG. 10 shows the correlation between the oxygen concentration in the second  
10 shielding gas 9 and the dimensions of the welded metal portion 5a, wherein FIG. 10(a)/(b) shows the results when the flow rate of the second shielding gas 9 is  $10/20L \cdot min^{-1}$ . As shown in FIG. 10, the width of the weld bead 6 is small and the welded metal portion 5a is formed deeply particularly when the oxygen concentration in the second shielding gas 9 is 2000-6000 vol. ppm, preferably 3000-6000 vol. ppm, and  
15 more preferably 3000-5000 vol. ppm. The comparison is made with the cases where the oxygen concentration is under 1000 vol. ppm or above 7000 vol. ppm.

[0049] FIG. 11 shows the correlation between the oxygen concentration in the second  
shielding gas 9 and the aspect ratio and the oxygen content (wt. ppm) of the welded  
metal portion 5a, wherein FIG. 11(a)/(b) shows the results when the flow rate of the  
20 second shielding gas 9 is  $10/20L \cdot min^{-1}$ . The aspect ratio of the welded metal portion 5a is defined as the ratio of depth (D) to width (W) of the welded metal portion 5a. As shown in FIG. 11, the aspect ratio of the welded metal portion 5a is higher when the second shielding gas 9 containing oxygen is used, as compared with the cases using pure argon gas. It is also noted that the aspect ratio of the welded metal portion 5a is  
25 relatively high when the oxygen concentration in the second shielding gas 9 is within the range of 2000-6000 vol. ppm, especially within the range of 3000-5000 vol. ppm.

[0050] Moreover, the oxygen concentration in the welded metal portion 5a increases with raise in the oxygen concentration in the second shielding gas 9. The oxygen



5 concentration in the welded metal portion 5a is about 200 wt. ppm when the oxygen concentration in the second shielding gas 9 reaches about 5000 vol. ppm, and is approximately a constant (220 wt. ppm) when the latter exceeds about 6000 vol. ppm. The aspect ratio of the welded metal portion 5a is relatively high when the oxygen concentration in the welded metal portion 5a is 70-220 wt. ppm, especially 70-200 wt. ppm, and the welded metal portion gets shallow when the oxygen concentration is outside the range. This is because the thickness of the oxide coating formed on the surface of the weld bead is overly large.

[0051] FIG. 12 is a graph showing the correlation between the oxygen concentration in the second shielding gas 9 and the thickness of the oxide coating formed on the surface of the welded metal portion 5a. FIG. 13 is a graph showing the correlation between the CO<sub>2</sub> concentration in the second shielding gas 9 and the thickness of the oxide coating formed on the surface of the welded metal portion 5a when CO<sub>2</sub> is used as the oxidative gas in the second shielding gas 9. As shown in the two graphs, the oxide coating gets thick when the concentration of the oxidative gas exceeds 6000 vol. ppm, while a thick oxide coating retards the convection in the molten pool 5 so that the welded metal portion 5a cannot be formed deeply. Meanwhile, the corrosion resistance and the appearance of the welded structure are also degraded. Therefore, the concentration of the oxidative gas is preferably 6000 vol. ppm or less, and more preferably 5000 vol. ppm or less.

25 [0052] Accordingly, when the composition of the second shielding gas 9 is set so that the oxygen concentration in the welded metal portion 5a is 70-220 wt. ppm, the welded metal portion 5a can be formed with a good shape. In addition, in the cases using a second shielding gas obtained by adding oxygen into argon gas, the shape of the welded

5 metal portion 5a and the welding efficiency both can be improved when the welding current is 160A, the welding speed is 2mm/sec and the oxygen concentration in the second shielding gas 9 is 2000-6000 vol. ppm.

[0053] Moreover, in the cases with other welding condition, for example, the cases where CO<sub>2</sub> or the like is used as the oxidative gas, the operation condition is also  
10 preferably set so that the oxygen concentration in the welded metal portion 5a is 70-220 wt. ppm.

#### Advantages of the Invention

[0054] The TIG welding equipment of this invention provides at least the following  
15 advantages. First of all, the electrode can be protected from being deteriorated by oxidation, since the first shielding gas composed of an inert gas is conducted surrounding the electrode. Therefore, the welded structure can be obtained with good welding quality.

[0055] Moreover, the first shielding gas composed of an inert gas can be supplied to the  
20 central region of the molten pool and the second shielding gas containing an oxidative gas to the peripheral region of the molten pool. Thereby, the molten pool can be supplied with oxygen in a required concentration, and the oxygen concentration in the peripheral region of the molten pool can be higher than that in the central region. Therefore, in the molten pool, the surface tension in the peripheral region having lower  
25 temperature and higher oxygen concentration is smaller, and that in the central region having higher temperature and lower oxygen concentration is larger. Consequently, inward convection is induced in the molten pool, and the molten pool can be formed deeply. Therefore, the welded metal portion can be formed deeply in the welded

5 object.

[0056] Furthermore, as compared with the conventional welding method using active flux, slag is hardly generated in this invention so that a slag removal operation is not required. Moreover, fume is also hardly generated during the welding operation. Therefore, the welding operation can be carried out easily.

10 [0057] In addition, since the welded metal portion can be formed deeply, occurrence of poor weld-penetration or reduction in welding efficiency can be prevented.

[0058] It will be apparent to those skilled in the art that various modifications and variations can be made to the structure of the present invention without departing from the scope or spirit of the invention. In view of the foregoing, it is intended that the  
15 present invention covers modifications and variations of this invention provided they fall within the scope of the following claims and their equivalents.